where: PDEN is the power density (dBW/4kHz) at GSO satellite in the direction of the Earth's horizon,
$L_{GSO \rightarrow NGSO}$ is the free space path loss between the GSO and NGSO satellite(dB),
G_r is the NGSO satellite receive gain in the direction of the GSO satellite(dBi).

1.1.2 Wanted NGSO MSS feeder link parameters

Using the parameters in Table 1 for planned NGSO MSS systems, the wanted carrier power, C (dBW/4kHz), at the NGSO satellite was calculated for each of the beams in the allotment plan from the following formula.

$$C = e.i.r.p._{es} - L_{ges \rightarrow NGSO} + G_{r,nadir}$$

where: $e.i.r.p._{es}$ is the gateway earth station e.i.r.p. (dB/4kHz),
$L_{ges \rightarrow NGSO}$ is the free space path loss between the gateway e.s. and the NGSO satellite(dB),
$G_{r,nadir}$ is the NGSO satellite receive gain at nadir(dBi).

Using the calculated C and I values, the worst case satellite-to-satellite C/I ratios at the NGSO satellite can be computed.

1.2.1 Interfering NGSO MSS feeder link parameters

The identical geometry described above was used to calculate the interfering power, I (dBW/4kHz), from the NGSO satellite into the ABS using the following formula;

$$I = e.i.r.p._{sat} - L_{NGSO \rightarrow GSO} + G_{max} + iso$$

where: $e.i.r.p._{sat}$ is the NGSO satellite e.i.r.p. density per channel (dBW/4kHz) from Table 1,
$L_{NGSO \rightarrow GSO}$ is the free space path loss between the NGSO and GSO satellites(dB),
G_{max} is the maximum ABS antenna gain from Section 1.7.2 of Appendix 30B,
iso is the relative ABS antenna gain from Figure 1 of Annex 1 of App 30B,

1.2.2 Wanted GSO ABS parameters

The wanted carrier power, C (dBW/4kHz), at each of the allotment plan beams was determined from the following formula;

$$C = esden_{ABS} - L_{es \rightarrow ABS} + G_{max} - 3\text{ dB}$$

where: $esden_{ABS}$ is the earth station e.i.r.p. density specified in the allotment plan (dBW/4kHz),
$L_{es \rightarrow ABS}$ is the free space path loss to a satellite in geostationary orbit,
G_{max} is the maximum ABS antenna gain from Section 1.7.2 of Appendix 30B,

Using the calculated C and I values, the worst case satellite-to-satellite C/I ratios at each ABS can be computed.

8

ATTACHMENT 8

Radio Communication Study Group
Fact Sheet

Study Group: TG 4/5 — Date: May 2, 1994
Document: USTG 4/5-5 (Rev. 2) — Ref:

Document Title: Feasibility of Sharing FSS Allocations in Reverse-Band Working Mode for Non-GSO MSS Satellites Feederlinks

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Purpose/Objective

To provide technical basis for a recommendation concerning the use of FSS allocations in reverse-band mode for non-GSO MSS feederlinks in a manner so as to minimize the probability of interference. This paper is only concerned with satellite to satellite interference.

Abstract

This paper analyzes the interference between GSO FSS transmissions and non-GSO MSS feederlink transmissions when the non-GSO feeder uplinks will operate in GSO FSS downlink bands, and non-GSO MSS feeder downlinks will operate in GSO FSS uplink bands. The following interference situations will be analyzed:

(1) GSO FSS satellite into non-GSO MSS satellite

(2) non-GSO MSS satellite into GSO FSS satellite

This study evaluates interference in the form of additional incremental noise temperature percentage due to such interference. Furthermore, this study provides simplified methodologies to analyze interference in these cases.

Study Group: US TG 4/5
Document: USTG 4/5-5 (Rev. 2)

Date: May 2, 1994
Ref: 4A/TEMP/182-E

UNITED STATES OF AMERICA

FEASIBILITY OF SHARING FSS ALLOCATIONS IN REVERSE-BAND WORKING MODE FOR NON-GSO MSS SATELLITE FEEDERLINKS

1. Introduction

The purpose of this study is to consider Reverse Band Working (RBW) for satellite-to-satellite interference and for the C, Ku, and Ka band and demonstrate that RBW is a viable solution for band sharing for feederlinks. RBW simplifies the complex interference problem associated with co-directional sharing. First, the interference scenarios in space and on earth are completely de-coupled and therefore can be considered separately. Furthermore, with RBW, the Geostationary Orbit (GSO) satellites transmitting towards earth will interfere with a non-GSO satellite only, in two extreme cases, transhorizon and the backlobe. Transhorizon is the situation where Non-GSO and a GSO satellite are in a transhorizon position and when satellites happen to point in each others main beam directions. The backlobe case is when a non-GSO satellite is directly beneath a GSO satellite, the non-GSO is in the main beam of GSO, and GSO is in the backlobe of the non-GSO. This document presents a simplified methodology for interference analysis between GSO and non-GSO satellites. Furthermore, it presents an extension of the ΔT/T figure of merit suggested by RR Appendix 29 used for single GSO's to analyze the level of interference in RBW between multiple non-GSO and GSO satellites. Document 8D/165-E presents a technique for RBW similar to the present work with computer simulations. The present document utilizes simple formulas that can be used in lieu of computer simulation.

2. Interference Methodology to Calculate ΔT/T for Single Satellite

RR appendix 29 provides a method of calculating the ΔT/T percentage to measure the level of interference between GSO FSS systems. This corresponds to a ratio of interference to noise (I/N) normalized to bandwidth of one hertz. In this study we also use ΔT/T , but we modify it to model various cases of GSO vs. non-GSO satellites. There are some differences between GSO FSS and the non-GSO cases. First, the relative distance of GSO and non-GSO satellites constantly changes with time, therefore ΔT/T itself varies with time. Second, In RR Appendix 29, the angular parameters are simply given in terms of one variable. This may be appropriate for GSO-FSS systems where these angles do not change with time and the antenna patterns are usually rotationally symmetric but are unsuitable for non-GSO's. It is necessary to develop a more appropriate expression representing all dynamic time dependent elements. The modified expression from RR appendix 29 between a GSO and non-GSO satellite can be written as

$$\left(\frac{\Delta T}{T}\right)(t) = \frac{p_t g_t(\theta_{tr}(t).\phi_{tr}(t)) g_r(\theta_{rt}(t).\phi_{rt}(t))}{kT\, l_{tr}(t)} . \qquad (1)$$

$\left(\frac{\Delta T}{T}\right)(t)$	is the percentage noise temperature rise at time t.
p_t	is the power density transmitted by the interferer
$g_t\left(\theta_{tr}(t),\phi_{tr}(t)\right)$	is the transmitter gain at the angles $\theta_{tr}(t)$ and $\phi_{tr}(t)$.
$\theta_{tr}(t)$	is the spherical theta angles centered at transmitter looking towards receiver at time t.
$\phi_{tr}(t)$	is the spherical phi angle centered at the transmitter looking towards receiver at time t.
$g_r\left(\theta_{rt}(t),\phi_{rt}(t)\right)$	is the gain of the receiver antenna at angles $\theta_{rt}(t)$, and $\phi_{rt}(t)$.
$\theta_{rt}(t)$	is the spherical theta angle centered at the receiver looking towards the transmitter at time t.
$\phi_{rt}(t)$	is the spherical phi angle centered at receiver looking towards the transmitter at time t.
$l_{tr}(t)$	is the spatial loss between transmitter and receiver at time t.
k	is Boltzmann's constant
T	is the noise temperature of the receiving satellite.

Equation (1) includes all the effects of satellite to satellite interference as a function of time. In its present form, it is complete but too complex for the present study. Later, we will simplify this expression for two extreme interference cases, transhorizon and backlobe cases.

2.1. Transhorizon Interference

Transhorizon is the case when two satellites are in line of sight over the horizon. In this special case, the distance between the two satellites is maximum and the spatial loss is high, but it is possible that the two satellites will be within main beams of one another. For this particular case, Equation (1) can be simplified by specifying the appropriate angular values of $\theta_{rt}(t)$, and $\phi_{rt}(t)$ to specify main lobes. In this case

$$\left(\frac{\Delta T}{T}\right)=\frac{EIRP_{o,ml}\cdot\frac{g_{r,ml}}{L_{th}}}{kT} \qquad (2)$$

where

$$EIRP_{o,ml}=g_{t,ml}\cdot p_t \qquad (3)$$

is the EIRP density looking into main antenna lobes

L_{th} is the spatial loss for the transhorizon case corresponding to the distance between the two satellites.

2.2. Backlobe Interference

Backlobe interference occurs when a non-GSO satellite is directly below a GSO satellite. In this case the distance is minimum and the non-GSO satellite is usually in the main lobe of GSO and the GSO is in the backlobe of the non-GSO satellite. For this particular case, Equation (1) can be simplified by specifying the appropriate angular values of $\theta_n(t)$, and $\phi_n(t)$ to specify backlobes. In this case

$$\left(\frac{\Delta T}{T}\right) = \frac{EIRP_{o,bl} \cdot \frac{g_{r,ml}}{L_{bl}}}{kT} \qquad (4)$$

where

$$EIRP_{o,bl} = g_{t,bl} \cdot p_t \qquad (5)$$

is the EIRP density looking into antenna backlobe

L_{bl} is the spatial loss for the backlobe interference case corresponding to the distance between the two satellites.

Depending on whether the GSO or non-GSO satellite is transmitting , appropriate EIRP densities and receiver antenna gains must be used.

3. Multiple Satellite Interference Calculation Methodology

Equation (1) represents the case where only one interferer and one victim is present. However, interference may occur between various combinations of multiple GSO and non-GSO satellites. RBW can also be applied to multiple constellations. The following equation describes the multiple satellite case in a compact form.

$$\left(\frac{\Delta T}{T}\right)_i(t) = \frac{1}{kT}\sum_{j=1}^{Ni(t)} \frac{p_{tj} g_{tj}\left(\theta_{j,i}(t),\phi_{j,i}(t)\right) g_{ri}\left(\theta_{i,j}(t),\phi_{i,j}(t)\right)}{l_{j,i}(t)} \qquad (6)$$

In the above equation, it is assumed that the index "i" represents the ith satellite which is being the victim of interference from Ni(t) satellites. And furthermore, index "j" designates the jth interfering satellite from the set of Ni(t) satellites

$\left(\frac{\Delta T}{T}\right)_i(t)$ is the percentage noise temperature increase of victim satellite i due to Ni(t) interfering satellites at time t. $Ni(t)$ is the number of interfering satellites visible to victim satellite i at time t.

p_t is the power density transmitted by the interfering satellite j.

$g_{tj}\left(\theta_{j,i}(t),\phi_{j,i}(t)\right)$ is the gain of the transmit antenna of the interfering satellite j at

	angles $\theta_{j,i}(t)$ and $\phi_{j,i}(t)$.
$\theta_{j,i}(t)$	is the spherical theta angle centered at the jth interfering satellite looking at the victim satellite i at time t.
$\phi_{j,i}(t)$	is the spherical phi angle centered at the interfering satellite j looking at the victim satellite i at time t.
$g_{ri}\left(\theta_{i,j}(t),\phi_{i,j}(t)\right)$	is the gain of the receiving antenna of the victim satellite i at angles $\theta_{i,j}(t)$ and $\phi_{i,j}(t)$.
$\theta_{i,j}(t)$	is the spherical angle theta centered at the victim satellite i looking towards the interfering satellite j at time t.
$\phi_{i,j}(t)$	is the spherical angle phi centered at the victim satellite i looking towards the interfering satellite j at time t.
$l_{j,i}(t)$	is the spatial loss between the victim satellite i and the interfering satellite j at time t.

Equation (6) describes the percentage interference for any victim GSO or non-GSO satellite i (the receiver) and an interfering satellite j (the transmitter). At any given time there can be many interfering satellites Ni visible to victim satellite i. Notice that this number changes with time, since the non-GSO systems are constantly in motion with respect to the GSO systems and that all angular values change as the vantage points of each satellite changes with time. Equation (6) is a good general expression that describes all possible cases of interference among various satellites regardless of being GSO or non-GSO. Here, we reduce this complex equation to a simpler form for quick calculation of interference among various satellites.

3.1. Simplified expression for ΔT/T for multiple satellites

Equation (6) for the multiple satellites can be reduced to an upper bound on the level of interference. First assuming that an isoflux pattern is used for the receive antenna, the term for the receive antenna gain over the spreading loss in equation (6) can be considered constant and thus moved outside of the summation.

$$\left(\frac{\Delta T}{T}\right)_i = \frac{1}{kT}\frac{g_r}{l}\sum_{j=1}^{Ni(t)} p_{tj}\, g_{tj} \qquad (7)$$

Selecting a typical two satellite case, i.e., a worst case, this equation can then be rewritten in the simple form below

$$\left(\frac{\Delta T}{T}\right)_{oneSat} = \frac{1}{kT\,l}\left(p_t g_t g_r\right) = \frac{1}{kT\,l} EIRP_o \cdot g_r \qquad (8)$$

which can be applied to calculate the interference due to a typical, average, or worst case satellite. This single satellite to single satellite interference can be found from Equation (1) or special cases of Equations (2) or (4). A measure of interference from all the satellites can then be thought of as a scaled up value of this value as

$$\left(\frac{\Delta T}{T}\right)_{max} = N_v\left(\frac{\Delta T}{T}\right)_{oneSat} \qquad (9)$$

For the worst case scenario, this can be considered as the upper bound for interference. A scale factor N_v can be found by multiplying total number of satellites N in the constellation, by the ratio of a surface S1 defined by the intersection of a interference cone and the sphere containing the non-GSO satellite orbits and total surface S2 defined by the barrel shaped surface formed by the non-GSO satellites constellation.

$$N_v = N\frac{S1}{S2} \qquad (10)$$

$$S2 = 4\pi r_2^2 - 2(2\pi r_2 h_2) \qquad (11)$$

$$S1 = 2\pi r_2 h_1$$

where the height of the cap for S1 is given by (12)

$$h_1 = r_2(1 - \cos(\beta)) \qquad (13)$$

and the height of the cap for the S2 is given by

$$h_2 = r_2(1 - \cos(\delta)) \qquad (14)$$

$$\beta = \pi - (\varepsilon + \alpha) \qquad (15)$$

$$\varepsilon = \sin^{-1}\left(\frac{r_1}{r_2}\sin\alpha\right) \qquad (16)$$

N_v	Scaling factor of number of satellite victims
N	Number of total satellites in non-GSO orbit
r_2	The orbit radius of non-GSO
r_1	The orbit radius of GSO
h_1	The height of spherical cap defining area S1
h_2	The height of spherical cap defining area S2
ß	Central angle of S1
∝	Nadir half angle of S1
ε	Corresponding elevation angle with added 90 degrees
δ	central angle complimentary to the inclination angle of satellite orbit

Equation (9) is an upper bound to equation (6). It shows that an upper limit of (Δ T/T)max can be obtained by simply finding (ΔT/T) of just one satellite as a typical or a worst case from Equations (1),(2), or (4) and then finding N_v, the scaling factor based on total number of satellites in view by using the simple Equation (10). This way, one can avoid complex Equation (6) in favor of a simpler typical or an upper bound analysis.

3.2. Example for the Determination of Interference Scale Factor

Table 1 gives an example of how to use the above relationships to find the scaling factor Nv for the simplified Equation (9). Three selected values of antenna beam's half angles are shown in three columns. The corresponding scaling number Nv gets smaller as the antenna half power beam width gets narrower. The scaling factors 2.46, 1, and 1 are obtained from antenna angles of 5, 2.5, and 1 Degrees, respectively (Note that any calculated scaling factor less than one is set to one).These numbers are then multiplied by the $\Delta T/T$ percentages obtained in the Tables 2-5, to obtain the upper limit $\Delta T/T$ as in Equation (9).

4. Interference Scenarios

For the case under consideration, there are four types of interference that can be considered. First two are the interference from GSO to non-GSO satellites in backlobe and transhorizon situations, and the second two are the non-GSO into GSO satellites in a backlobe and transhorizon situations.

4.1. Interference from GSO Satellites into non-GSO Satellites

4.1.1. Backlobe Interference

Table 2 provides an example of interference from a GSO satellite into a non-GSO satellite in the backlobe situation as described by Equation (4). This can be considered as the $\Delta T/T$ of one satellite in Equation (9). The parameters selected to be typical of INTELSAT for the GSO and LEO-D for non-GSO satellite. In Table 2, the main lobe gain for the LEO-D satellite antenna is -2 dBi, and the back lobe isolation is 35 dB.

This level of isolation is easily achievable and may even be more due to the blocking by the satellite body. The antenna used is an Isoflux type design which will have --2 dBi gain at nadir, maximum of 7 dBi gain at around ±26°, and then falls very rapidly below the zero level at ±55. This antenna utilizes advanced phased array technologies to achieve these levels of gain and high backlobe isolation. The reason the nadir gain is below isotropic, is because the antenna efficiencies at these design are low. But this is acceptable since it is a trade- off for realization of the Isoflux radiation pattern and high backlobe isolation. The backlobe gain used in Table 2 is therefore -37 dBi .

It is shown that the interference in all C, Ku, and Ka bands is negligible. These $\Delta T/T$ values at the bottom of table 2 can be multiplied by the corresponding scale factors Nv obtained in Table 1 to obtain the $\Delta T/T$ maximum as suggested by Equation (9). These low interference levels are achievable even if the backlobe isolation is less than 35 dB, i.e. 10 dB, for which the $\Delta T/T$ will be 0.01%, 0.02%, and 0.00% for the C, Ku, and Ka bands respectively. Even with this level of isolation, there is considerable interference margin.

4.1.2. Transhorizon Interference

Table 3 provides an example of interference from a GSO satellite into a non-GSO satellite transhorizon situation as described by Equation (2). This can be considered as the $\Delta T/T$ of one satellite in Equation (9). The parameters selected to be typical of INTELSAT for the GSO and LEO-D for non-GSO satellite. It is shown that the interference in all C, Ku, and Ka bands is negligible. These $\Delta T/T$ values at the bottom of table 3 can be multiplied by the corresponding scale factors Nv obtained in Table 1 to obtain the $\Delta T/T$ maximum as suggested by Equation (9).

4.2. Interference from non-GSO Satellites into GSO Satellites

4.2.1. Backlobe Interference

Table 4 provides an example of interference from a non-GSO satellite into a GSO satellite in the backlobe situation as described by Equation (4). This can be considered as the $\Delta T/T$ of one satellite in Equation (9). The parameters selected to be typical of INTELSAT for the GSO and LEO-D for non-GSO satellite. In Table 4, the main lobe gain for the LEO-D satellite antenna is -2 dBi, and the back lobe isolation is 35 dB. This level of isolation is easily achievable and may even be more due to the blocking by the satellite body. The backlobe gain used in Table 4 is therefore -37 dBi , as discussed in section 4.1.1. It is shown that the interference in all C, Ku, and Ka bands is negligible. These $\Delta T/T$ values at the bottom of table 4 can be multiplied by the corresponding scale factors Nv obtained in Table 1 to obtain the $\Delta T/T$ maximum as suggested by Equation (9). It can be demonstrated that the interference levels will still be negligible, even if we used an isolation level less than 35 dB, i.e., 10 dB, the $\Delta T/T$ levels will be 0.00%, 0.01%, and 0.01% for C, Ku, and Ka bands respectively.

4.2.2. Transhorizon Interference

Table 5 provides an example of interference from a non-GSO satellite into a GSO satellite transhorizon situation as described by Equation (2). This can be considered as the $\Delta T/T$ of one satellite in Equation (9). The parameters selected to be typical of INTELSAT for the GSO and LEO-D for non-GSO satellite. It is shown that the interference in all C, Ku, and Ka band is negligible. These $\Delta T/T$ values at the bottom of table 5 can be multiplied by the corresponding scale factors Nv obtained in Table 1 to obtain the $\Delta T/T$ maximum as suggested by Equation (9).

4.3. Parametric Interference Plots

Figures 1,2, and 3 are three parametric plots generated by using Equation (1) to develop some insight in the complex interference picture. To make it possible to use the same set of plots for analyzing the interference from or to GSO or non-GSO's, the entire numerator of Equation (1) is used as the parameter of variation. Thus by regrouping the numerator into eirp and gr, the parameter is selected to be the eirp density in the direction of interfered with satellite times the receive antenna gain in the direction of the transmitting satellite designated as [eirp.gr(dBW/Hz)] in the legend of the plots of Figure 1,2, and 3.

4.3.1. $\Delta T/T$ Analysis at C-Band

To provide a simple means of analysis of the percent $\Delta T/T$ for interference between a GSO and a non-GSO satellite or vice versa in the C-Band, some parametric plots can be developed. The parametric plots of Figure 1 are based on Equation (1). It uses eirp density in the direction of interfered with satellite, times the receive antenna gain in the direction of the transmitting satellite designated as [eirp.gr(dBW/Hz)] in the legend of the plots of Figure 1 as a variational parameter to plot the $\Delta T/T$ as a function of Range. The frequency used is 6 GHz and T = 700. The vertical scale is in percent and the horizontal scale is in 1000 of km's. Furthermore, each trace corresponds to the parameter [eirp.gr(dBW/Hz)] . Movement up and down a trace corresponds to larger and smaller range between the two satellites involved. A range of [eirp.gr(dBW/Hz)] of -8 to -28 dBW/Hz in 2 dB increments is shown. These plots can be used to obtain an acceptable distance between two satellites for a given [eirp.gr(dBW/Hz)] and for a level of interference. For example, Figure 1 shows that to obtain a $\Delta T/T$ of 4% or below, the range between the two satellites should be equal or greater than 40000 km for the combination of [eirp.gr(dBW/Hz)] = -14 dBW/Hz.

4.3.2. $\Delta T/T$ Analysis at Ku-Band

Figure 2 shows similar parametric plots to Figure 1 for the Ku band. The frequency used is f = 14 GHz, and T = 850. A range of [eirp.gr(dBW/Hz)] of -2 to -22 dBW/Hz in 2 dB increments is shown.

4.3.3. $\Delta T/T$ Analysis at Ka-Band

Figure 3 shows similar parametric plots to Figure 1 for the Ka band. The frequency used is f = 30 GHz, and T = 1000. A range of [eirp.gr(dBW/Hz)] of +4 to -14 dBW/Hz in 2 dB increments is shown.

5. Summary and Conclusion

This report presents a simplified methodology for analyzing interference between GSO and non-GSO satellites. Simplified Equations (2) and (4), provide quick means to calculate $\Delta T/T$ as a measure of interference. This measure was selected to be consistent with RR appendix 29. The complex case of multiple satellite interference was further simplified to an upper bound of interference as provided by Equation (9). An interference scaling methodology was also provided in equation (10). Backlobe and transhorizon cases for interference between GSO and LEO-D type non-GSO satellites were considered which showed that the levels are very low and acceptable for RBW working. Furthermore, some useful parametric plots based on Equation (2) was provided for C, Ku, and Ka bands to serve as quick tradeoff analysis tool for range, power and interference levels. The results of the space-to-space analyses demonstrate that RBW is a viable means to share FSS frequency bands for feeder link of non-GSO MSS systems. The extreme cases of interference in the transhorizon and backlobe case provide negligible levels of interference as illustrated in Tables 2-5. This suggests that RBW may be used without the necessity of coordination.

Table 1. Calculation of Interference Scale Factor

	Beam 1	Beam 2	Beam 3	Units
Alpha=	5.00	2.50	1.00	Degrees
Earth Radius	6378.00	6378.00	6378.00	km
GSO Orbit Height	35786.00	35786.00	35786.00	km
NGSO Orbit Height	1406.80	1406.80	1406.80	km
NGSO orb. incl. angle	52.00	52.00	52.00	Degrees
Number of NGSO sats	48.00	48.00	48.00	
r1=	42164.00	42164.00	42164.00	km
r2=	7784.80	7784.80	7784.80	km
Epsilon=	151.83	166.33	174.58	Degrees
Beta=	23.17	11.17	4.42	Degrees
h1=	627.68	147.33	23.19	km
h2=	1650.06	1650.06	1650.06	km
S1=	3.07E+07	7.20E+06	1.13E+06	sqr-km
S2=	6.00E+08	6.00E+08	6.00E+08	sqr-km
Nv (Calculated)	2.46	0.58	0.09	
Nv (Used)	2.46	1.00	1.00	

Table 2 Backlobe Interference from a GSO into a non-GSO satellite

	C-Band	Ku-Band	Ka-Band	Units
Earth Radius	6378.00	6378.00	6378.00	km
GSO Orbit Height	35786.00	35786.00	35786.00	km
NGSO Orbit Height	1406.80	1406.80	1406.80	km
Range	34379.20	34379.20	34379.20	km
T	700.00	850.00	1000.00	K
T	28.45	29.29	30.00	dBK
k	-228.60	-228.60	-228.60	dBW/k
frequency	4000.00	11000.00	20000.00	MHz
GSO Tx Bandwidth	36.00	112.00	112.00	MHz
Bandwidth	75.56	80.49	80.49	dB-Hz
GSO Ant. ml-Gain	29.00	40.00	44.00	dBi
NGSO Ant. bl Isolation	35.00	35.00	35.00	dB
NGSO Ant. ml Gain(gr,ml	-2.00	-2.00	-2.00	dBi
NGSO Ant. bl-Gain	-37.00	-37.00	-37.00	dBi
Power into GSO ant.	14.80	21.00	13.00	dBW
GSO EIRP density	-31.76	-19.49	-23.49	dBW/Hz
Path Loss	195.22	204.00	209.20	dB
Delta Noise	-35.38	-31.90	-41.09	dBK
DeltaT/T	-63.83	-61.19	-71.09	dB
Delta T/T	0.00%	0.00%	0.00%	Percent

Table 3 Transhorizon Interference from a GSO into a non-GSO satellite

	C-Band	Ku-Band	Ka-Band	Units
Earth Radius	6378.00	6378.00	6378.00	km
GSO Orbit Height	35786.00	35786.00	35786.00	km
NGSO Orbit Height	1406.80	1406.80	1406.80	km
Range	46142.48	46142.48	46142.48	km
T	700.00	850.00	1000.00	K
T	28.45	29.29	30.00	dBK
k	-228.60	-228.60	-228.60	dBW/k
frequency	4000.00	11000.00	20000.00	MHz
GSO Tx Bandwidth	36.00	112.00	112.00	MHz
Bandwidth	75.56	80.49	80.49	dB-Hz
GSO Ant. ml-Gain(gt,ml)	26.00	40.00	44.00	dBi
NGSO Ant. ml-Gain(gr,ml)	-2.00	-2.00	-2.00	dBi
Power into GSO ant.	14.80	21.00	13.00	dBW
GSO EIRP density	-34.76	-19.49	-23.49	dBW/Hz
Path Loss	197.77	206.56	211.75	dB
Delta Noise	-5.94	0.55	-8.64	dBK
DeltaT/T	-34.39	-28.75	-38.64	dB
DeltaT/T	0.04%	0.13%	0.01%	percent

Table 4 Backlobe Interference from non-GSO into a GSO satellite

	C-Band	Ku-Band	Ka-Band	Units
Earth Radius	6378.00	6378.00	6378.00	km
GSO Orbit Height	35786.00	35786.00	35786.00	km
NGSO Orbit Height	1406.80	1406.80	1406.80	km
Range	34379.20	34379.20	34379.20	km
T	700.00	850.00	1000.00	K
T	28.45	29.29	30.00	dBK
k	-228.60	-228.60	-228.60	dBW/k
frequency	6000.00	14000.00	30000.00	MHz
Bandwidth	132.00	132.00	264.00	MHz
Bandwidth	81.21	81.21	84.22	dB-Hz
GSO Ant. ml-Gain(gr,ml)	29.00	41.00	48.00	dB
NGSO Ant. bl Isolation	35.00	35.00	35.00	dB
NGSO Ant. ml-Gain(gt,ml	-2.00	-2.00	-2.00	dBi
NGSO Ant. bl-Gain	-37.00	-37.00	-37.00	dBi
Power into NGSO ant.	14.00	18.50	19.50	dBW
NGSO EIRP density	-104.21	-99.71	-101.72	dBW/Hz
Path Loss	198.74	206.10	212.72	dB
Delta Noise	-45.34	-36.20	-37.83	dBK
DeltaT/T	-73.80	-65.50	-67.83	dB
DeltaT/T	0.00%	0.00%	0.00%	percent

Table 5 Transhorizon Interference from a non-GSO to a GSO satellite

	C-Band	Ku-Band	Ka-Band	Units
Earth Radius	6378.00	6378.00	6378.00	km
GSO Orbit Height	35786.00	35786.00	35786.00	km
NGSO Orbit Height	1406.80	1406.80	1406.80	km
Range	46142.48	46142.48	46142.48	km
T	700.00	850.00	1000.00	K
T	28.45	29.29	30.00	dBK
k	-228.60	-228.60	-228.60	dBW/k
frequency	6000.00	14000.00	30000.00	MHz
Bandwidth	132.00	132.00	264.00	MHz
Bandwidth	81.21	81.21	84.22	dB-Hz
GSO Ant. ml-Gain(gr,ml)	29.00	41.00	48.00	dBi
NGSO Ant. ml-Gain(gt,ml	-2.00	-2.00	-2.00	dBi
Power into NGSO ant.	14.00	18.50	19.50	dBW
NGSO EIRP density	-69.21	-64.71	-66.72	dBW/Hz
Path Loss	201.30	208.65	215.27	dB
Delta Noise	-12.90	-3.76	-5.39	dBK
DeltaT/T	-41.35	-33.05	-35.39	dB
DeltaT/T	0.01%	0.05%	0.03%	percent

Figure 1. ΔT/T percentage as a function of slant range for various [eirp.gr(dBW/Hz)] levels in the direction of interfered with satellite, at T=700 for the C band.

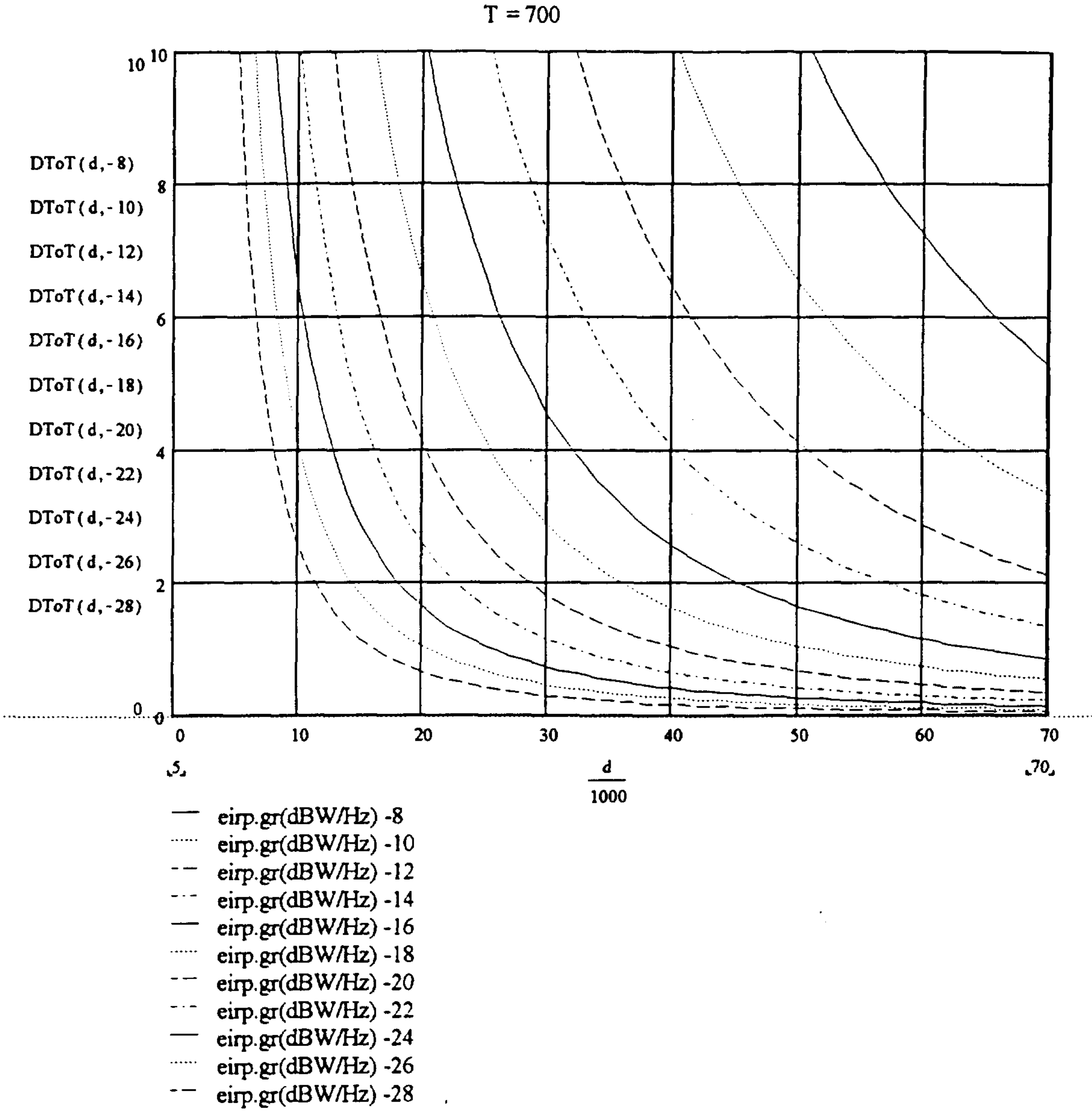


Figure 2. ΔT/T percentage as a function of slant range for various [eirp.gr(dBW/Hz)] levels in the direction of interfered with satellite, at T=850 for the Ku band.

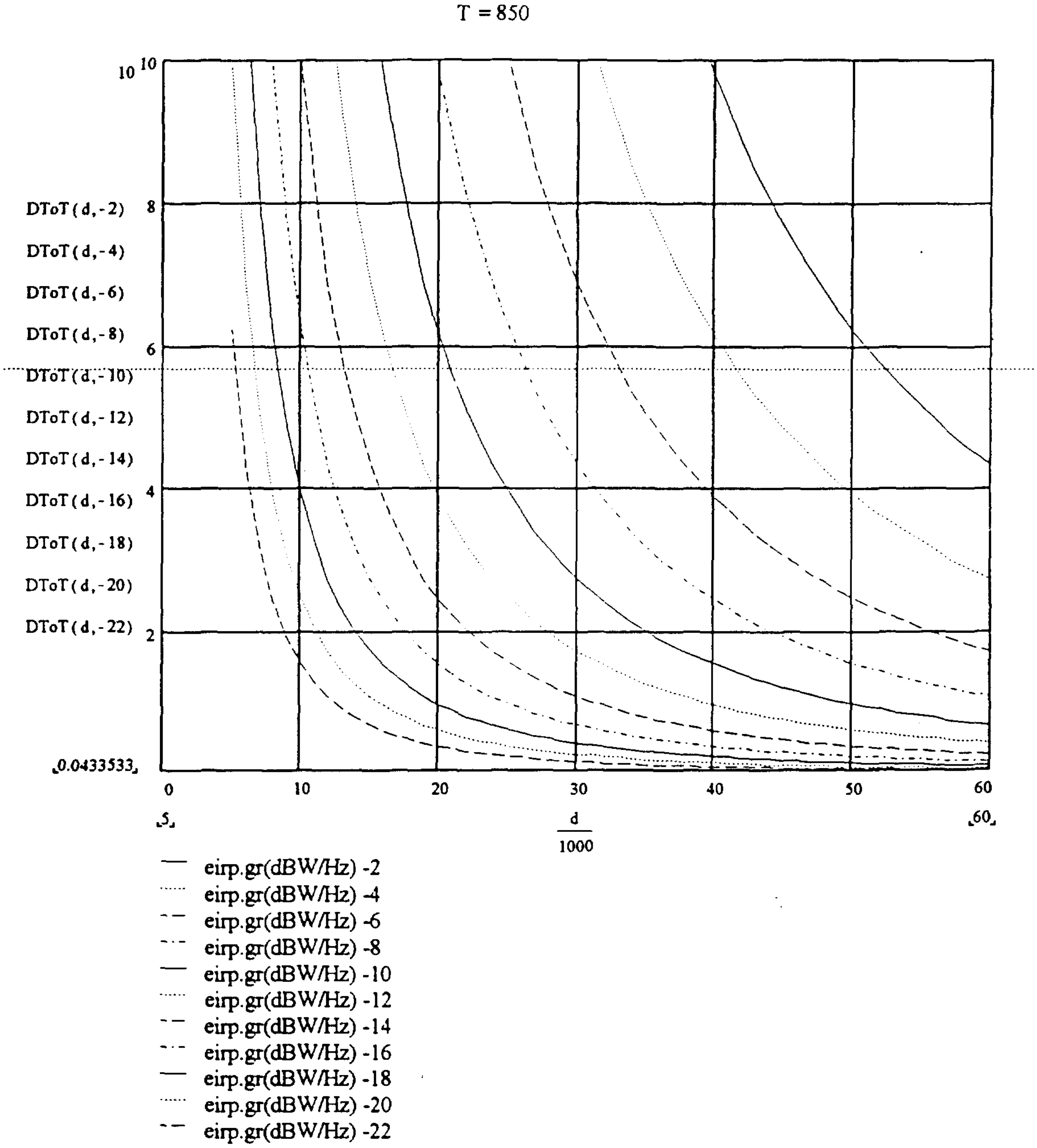
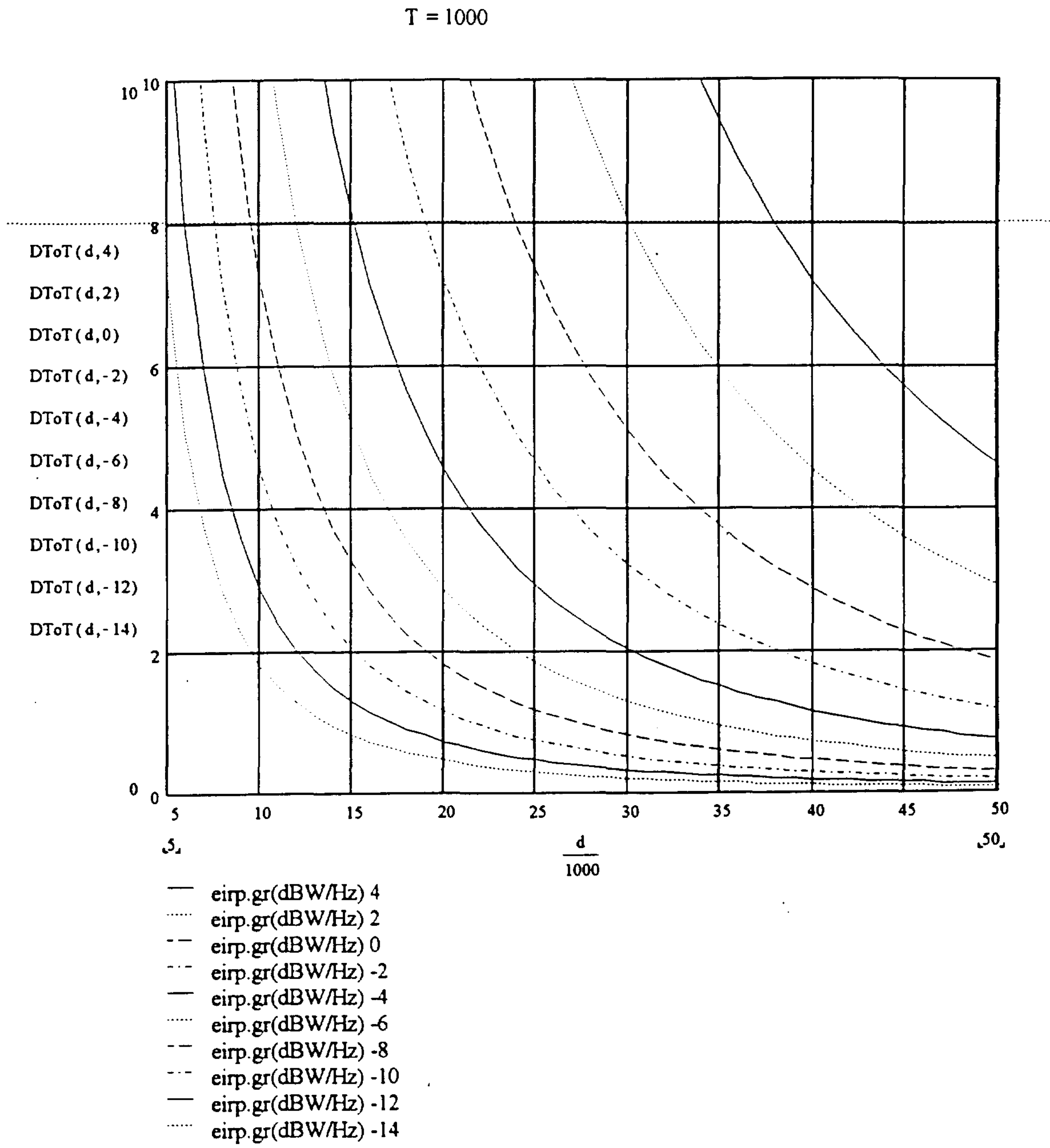


Figure 3. ΔT/T percentage as a function of slant range for various [eirp.gr(dBW/Hz)] levels in the direction of interfered with satellite, at T=1000 for the Ka band



9

ATTACHMENT - 9

Study Group: US TG 4/5 | Date: April 29,1994

Document: USTG 4/5-4 | Ref: 4A/TEMP/182-E

UNITED STATES OF AMERICA
Working Document towards a Draft New Recommendation

FSS Earth Station to MSS Land Earth Station (LES) Coordination Distances in Reverse Band Working (RBW) Mode

1. Introduction

If Reverse Band Working (RBW) is used for MSS feederlinks, the radiation from FSS earth stations can interfere into MSS Land Earth Stations (LES), and vice versa. This interference can be kept at acceptable levels if a minimum distance is imposed between FSS and MSS earth stations. Doc. 4A/TEMP/182-E gives a method for calculating coordination distances and shows that RBW for non-GSO feederlinks is feasible. For INMARSAT or scaled INMARSAT type non-GSO intermediate circular orbits (ICOs) and INTELSAT FSS parameters at C and Ku bands, the coordination distances were found to be between 100 and 160 km. These results were based on a Mode 1 and a type of Mode 2 propagation described in ITU-R Recommendation 847, and assumed that the non-GSO earth station was located in zone A2 (all land, no coastal areas). The present paper proposes a similar approach for calculating coordination distances, but uses parameters for the GSO earth stations based on ITU-R Recommendation 848 (dealing with bidirectional use of frequency bands), and considers allowable interference power based on Recommendation 847 rather than on Appendix 28. An example based on parameters applicable to the non-GSO MSS system designated LEO-D is provided to illustrate use of this approach.

2. Link Parameters:

2.1 FSS System Parameters

The parameters used to calculate interference levels and coordination distances are given in Table 1. The earth station noise temperatures are the ones recommended in Recommendation 848 for earth stations operating in bidirectionally allocated frequency bands. Earth station power densities used are typical high values, which lead to conservative estimates for coordination distances. The earth station radiation pattern, based on Recommendations 580-2 and 465, is assumed to be:

$$\begin{aligned}
G_{FSS}(\theta) &= 29 - 25\log(\theta)\,(dBi)\ for\ 1^0 \le \theta \le 20^0 \\
G_{FSS}(\theta) &= -3.5\ for\ 20^0 < \theta < 26.3^0 \\
G_{FSS}(\theta) &= 32 - 25\log(\theta)\ for\ 26.3^0 < \theta < 48^0 \\
G_{FSS}(\theta) &= -10\ for\ \theta > 48^0
\end{aligned} \qquad \text{Eq.(1)}$$

In the calculations, the minimum elevation angle for FSS earth stations is taken to be 10 degrees.

2.2 Non-GSO System parameters

The non-GSO MSS system LES antenna pattern is assumed to be the same as in Eq. (1). The other parameters are taken to be the ones expected for an example MSS system (LEO-D). In particular, this system uses CDMA carriers. The minimum elevation angle for the LES is taken as 10 degrees.

2.3 Interference Criteria

ITU-R Recommendation 847 recommends that coordination distances be calculated based on a threshold level of permissible interference, $\mathcal{P}_r(p)$, of an interfering emission (dBW) in the reference bandwidth to be exceeded for no more than p % of the time at the output of the receiving antenna of the interfered-with earth station, the interfering emission originating from a single source.

2.3.1 MSS earth station interference into FSS earth station

ITU-R Recommendation 847 gives criteria and parameters to be used for determining coordination distances between an FSS earth station and a terrestrial station. The same criteria are used here for determining acceptable interference into FSS earth stations. Eq.(3) of Recommendation 847, reproduced below, gives the threshold interference level to be exceeded no more than p% of the time at the FSS antenna output:

$$\mathcal{P}_r(p) = 10\log(k\mathcal{T}_r\mathcal{B}) + \mathcal{N}_L + 10\log(10^{\mathcal{M}_s/10} - 1) - \mathcal{W}(dBW) \qquad \text{Eq.(2)}$$

where:

k: Boltzmann's constant

$\mathcal{T}_r$: thermal noise temperature of the receiving system (K), at the receiving antenna output terminal

$\mathcal{N}_L$: link noise contribution, taken as 1 dB for fixed satellite links

B: reference bandwidth (Hz), ie the bandwidth in the interfered-with system over which thepower of the interfering emission can be averaged

p: percentage of the time during which the interference from one source may exceed the threshold value; since the entries of interference are not likely to occur simultaneously, $p = p_0 / n$

p_0: percentage of time during which the interference from all sources may exceed the threshold value

n: number of equivalent, equal level, equal probability entries of interference, assumed to be uncorrelated for small percentages of time

$\mathcal{M}_s$: link performance margin (dB)

W: an equivalence factor (dB) relating interference from interfering emissions to that caused, alternatively, by the introduction of additional thermal noise of equal power in the reference bandwidth.

The values of the parameters to be used in this equation are given in Table 2 of Recommendation 847, except for T_e, which is given in Recommendation 848 and listed in Table 1 of this paper. The rest of the parameters are listed in Table 2 of this paper.

2.3.2 FSS earth station interference into MSS LES:

For this situation, Recommendation 849 (on coordination areas for earth stations operating with non-GSO space stations) could be used in determining interference criteria in cases where the specific characteristics of the LES are unknown. However, Recommendation 849 does not give parameters for MSS non-GSO systems. The present paper takes the approach of calculating coordination distances based on acceptable interference levels into the FSS earth station from the MSS, and then using these distance values to see what level of interference is seen at the LES due to the FSS earth station.

2.4 Calculation of coordination distances

2.4.1 Minimum permissible transmission loss

The required coordination distance is calculated from the minimum permissible transmission loss, which is obtained from Eq.(2) of Recommendation 847 as follows:

$$L_b(p) = P_t + G_t + G_r - P_r(p)(dB) \qquad \text{Eq.(3)}$$

where:

$L_b(p)$: minimum permissible basic transmission loss (dB) for p% of the time

P_t: maximum available transmitting power level (dBW) in the reference bandwidth at the input to the antenna of an interfering station

G_t: gain (dBi) of the transmitting antenna of the interfering station towards the interfered with station

G_r: gain (dBi) of the receiving antenna of the interfered-with station in the direction of the interfering station

Using Eq.(1) for the antenna gains G_t and G_r and Eq.(2) for $P_r(p)$ gives $L_b(p)$.

2.4.2 Coordination distances using propagation Mode 1:

Recommendation 847 gives the relationship between $L_b(p)$ and coordination distance, for propagation Mode 1, defined as great circle propagation mechanisms. As discussed in Doc. 4A/TEMP/182-E, use of this mode, which is a short-term propagation mode, yields worst-case propagation distances, because the probability of the two earth stations being lined up and pointing at each other at their lowest elevation angles, at a time that coincides with an event (eg ducting) causing short-term propagation loss, is very small. Thus the actual percentage of time that the interference exceeds the chosen threshold will be less than the p% defined in the previous section.

The relevant steps from Recommendation 847 used in calculating coordination distance are summarized below.

Assuming that most of the LESs are located on land, far from coastal areas (zone A2 of propagation Model in Recommendation 847), the values of $L_b(p)$ are given by

$$L_b(p) = L_1 + A_1$$

$$L_b(p) = \beta_1(p)d_1 + A_1$$

with

$$A_1 = 120 + 20\log f + \log p + 5p^{0.5} + A_h$$

where :

f: *frequency* (GHz)

$A_h = 0\ for\ \theta > 0$

$d_1 = distance$

$$\beta_1(p) = 0.01 + \beta_{dz}(p) + \beta_0 + \beta_{vz}(dB/km)$$

$$\beta_{dz}(p) = C_1 + C_2\log f + C_3 p^{C_4}(dB/km)$$

Eq.(4)

The coefficients $\beta_0, \beta_{vz}, C_1, C_2, C_3, C_4$ in Eq.(4) are specified in Recommendation 847 as a function of frequency and zone (A2 in this case).

2.4.3 Application to present LES/FSS earth station coordination problem

Using the values of $\beta_0, \beta_{vz}, C_1, C_2, C_3, C_4$ specified in Recommendation 847, and substituting into the above equations leads to the following equation, for p% = 0.002%, which is the appropriate value of p from Table 2 of Recommendation 847, for the types of FSS earth stations assumed.

$$L_b(0.002) = 129.6 + 0.17312 d_1 (at 4 GHz)$$
$$L_b(0.002) = 138.3 + 0.20369 d_1 (at 11 GHz) \qquad \text{Eq.(5)}$$
$$L_b(0.002) = 143.5 + 0.31220 d_1 (at 20 GHz)$$

$$L_b(0.002) = 132.7 + 0.176964 d_1 (at 6 GHz)$$
$$L_b(0.002) = 141.3 + 0.231291 d_1 (at 14 GHz) \qquad \text{Eq.(6)}$$
$$L_b(0.002) = 150.1 + 0.349339 d_1 (at 30 GHz)$$

Table 2 shows the values of the various parameters used in calculating the coordination distances for interference from the LEO LES into the FSS earth station, which occurs at 4, 11 or 20 GHz with RBW. It also lists the values of the path loss coefficients to be used for calculating interference from the FSS earth station into the LES, which occurs at 6, 14 or 30 GHz, again with RBW.

The spreadsheet of Table 3 shows the calculated coordination distances, using Eqs.(1), (3), (4), (5),and (6). Recommendation 847 specifies that the minimum coordination distance is 100 km. Therefore, in cases where the spread-sheet shows distances less than 100 km, this is the value to be used. Table 3 shows that the coordination distances are about 100 km at Ka band, 126 km at Ku band, and 258 km at C-band. For these coordination distances, the table also shows the received interference into the LES from the FSS earth station. The received ratios (I/No) of interference to thermal noise density at the LES are found to be about -4, -1 and -11 dB for C, Ku and Ka band respectively. While little work has been done to date on acceptable interference power into MSS feeder links, it is suggested that the values of interference shown in the table may be acceptable, considering the fact that they are worst case values which would only occur during a worst case pointing situation for very small periods of time.

2.4.4 Propagation Mode(2)

Recommendation 847 also gives a propagation mode known as Mode(2), for hydrometeor (rain) scattering. The minimum coordination distance for this mode is specified to be 100 km. This minimum is also prescribed for Propagation Mode 1. (Therefore, in Table 3, for Ka band, the coordination distance calculated was less than 100 km. (82 km.), but is shown as 100 km.) Also, Recommendation 849, on coordination areas for earth stations operating with non-GSO spacecraft, states that this mode is not considered, because "the probability of not exceeding the required level of transmission loss is greatly reduced by antenna motion in the case of earth station antennas with relatively high gain or by the relatively high transmission losses associated with earth station antennas having relatively low gain. In all cases, the propagation Mode 2 distances would be less than the propagation Mode 1 (great-circle) distances." For this reason, Mode 2 is not considered here.

2.5 Sensitivity to elevation angle:

The worst case coordination distances are found by assuming that the FSS antenna and the LES antenna are pointing at each other, with each one operating at its minimum elevation angle (taken here as 10 degrees). If either of the elevation angles is increased or the relative azimuth between the two antennas increases, the antenna gain decreases according to Eq. (1), and leads to lower coordination distances (subject to the minimum of 100 km). As an example, Figure 1 shows C and Ku band coordination distances for LEO-D as a function of LES elevation angle, assuming that the FSS elevation angle is 10 degrees, and that that their relative azimuth is 180 degrees (i.e., they point "towards" each other). For Ka band, since the coordination distance was less than 100 km to begin with, no reduction in distance occurs as elevation angle changes.

3.0 Conclusions

Coordination distances between FSS earth stations and LEO-D Land Earth Stations are found to be about 100 km at Ka band, 126 km at Ku band, and 258 km at C-band. These are worst case coordination distances, based on permissible short-term interference

(0.002% of the time), assuming that the two earth stations happen to be radiating towards each other, with each operating at its minimum elevation angle of 10 degrees, and that a short-term interference event such as ducting occurs at the same time. Therefore, the coordination distances calculated are very conservative. It should also be noted that when LESs are being installed, they should be located north of FSS earth stations in the northern hemisphere, and to the south of FSS earth stations in the southern hemisphere wherever possible. In such cases, the coordination distances can be reduced below the values calculated here.

Table 1: Assumed FSS System Parameters

	C band	Ku band	Ka band
Earth Station Noise Temperature (K), from ITU-R IS-848	75	150	300
Earth Station powerdensity (dBW/Hz)	-34.3 (INTELSAT SCPC carriers)	-43.2 (INTELSAT IDR carriers)	-43.2 (INTELSAT future, IDR carriers)

Table 2: Parameters and values used in coordination calculations

	C band	Ku band	Ka band
p%	0.002	0.002	0.002
NL,dB	1	1	1
Ms,dB	2	4	6
W,dB	0	0	0
Pr(p)-10logkTB,dBW	-1.32923	2.795192	5.743724
k, dBJ/K	-228.6	-228.6	-228.6
T,K	75	150	300
B,MHz	1	1	1
kTB,dBW	-149.849	-146.839	-143.829
Pr(p) for part A.,dBW	-151.179	-144.044	-138.085
f,GHz	4	11	20
A1	129.5658	138.3525	143.5452
beta0	0.006147	0.007223	0.010366
betavz	0.000921	0.008447	0.100832
betadz	0.156048	0.178015	0.190997
beta	0.173117	0.203685	0.312196
f,GHz	6	14	30
A1	136.5648	144.2923	151.2432
beta0	0.006377	0.008002	0.018486
betavz	0.002145	0.01672	0.079799
betadz	0.164853	0.183252	0.199802
beta	0.183376	0.217974	0.308086

Table 3: Interference between LEO-D LES and INTELSAT type FSS earth stations, with RBW

A. Interference from LEO-D LES into FSS earth station

Frequency band		C-band	Ku band	Ka band
Frequency	GHz	4	11	20
LES power density	dBW/Hz	-45	-48	-48
LES elevation angle	degrees	10	10	10
LES antenna gain	dBi	4	4	4
FSS elevation angle	degrees	10	10	10
FSS azimuth earth station deviation	degrees	0	0	0
Corresponding off-axis angle	degrees	10	10	10
Corresponding antenna gain	dBi	4	4	4
Reference bandwidth	dB-Hz	60	60	60
Permissible interference	dBW	-151.179	-144.044	-138.085
Minimum permissible loss	dB	174.1786	164.0439	158.0851
Coordination distance,d1	km	257.7033	126.133	100
(Minimum d1 is 100 km)				

B. Interference from FSS earth station into LEO-D LES

Frequency	GHz	6	14	30
FSS earth stn. power density	dBW/Hz	-34.3	-43.2	-43.2
FSS elevation angle	degrees	10	10	10
FSS azimuth earth station deviation	degrees	0	0	0
Corresponding off-axis angle	degrees	10	10	10
FSS antenna gain	dBi	4	4	4
LES elevation angle	degrees	10	10	10
Corresponding antenna gain	dBi	4	4	4
Reference bandwidth *	dB-Hz	61	61	61
Coordination distance,d1	km	257.7033	126.133	100
Path loss	dB	183.8213	171.786	182.0518
Interference received	dBW	-149.121	-145.986	-156.252
Thermal noise	dBW	-145	-145	-145
I/No	dB	-4.12131	-0.98596	-11.2518

* 10 log (the reference channel bandwidth), which for the LEO-D system is 1.23 MHz